[TRANSLATION]

AMENDMENT UNDER ARTICLE 34 PCT

FILED OCTOBER 8, 2003

laser are disclosed, and the operation of the means will be described.

[0036] In order to accomplish the above object, the present invention provides a light source device having a light source element from which output light is emitted to outside via a multiple scattering optical system, wherein the multiple scattering optical system includes at least a first region that is located adjacent to the light source element, and a second region that abuts on the first region and reaches the outside and, of the first and second regions, at least the first region contains scatterers, and a density of the scatterers in the first region is higher than a density of scatterers in the second region. The second region may have a lens portion. Alternatively, the second region may serve as a magnifier for at least a principal portion of a secondary planar light source formed at an interface between the first region and the second region.

[0037] According to the light source device of the above-mentioned construction, by generating mainly in the first region the multiple scattering that sufficiently reduces the spatial coherency of the output light from the light source element and controlling the angular distribution characteristic of the radiant intensity mainly by the magnifier of the second region, the optimization of

long as the scatterers are spatially distributed at random. Typically, a preferable manufacturing condition can be found within a dispersion density range of about 0.5 vol% to 30 vol%. However, in the case of high density scatterers in which the scatterers can be brought in direct contact with one another, an undesirable phenomenon of possibly occurs from the viewpoint of speckle reduction. One cause is a problem of the secondary cohesion of the particles, and the other cause is the fact that the randomness is reduced due to the dense structure of the spatial distribution of the scatterers. It is important for managing the actual manufacturing process to clarify the necessary minimum dispersion density within the desired range of the scatterer particle size in order to efficiently reduce the spatial coherency by means of an optical system that is as minute as possible.

[0050] Accordingly, it was found that, by distributing the average nearest neighbor distance of the scatterers mainly dispersed in the first region so that the distance falls within about twenty times the particle size mode Ds of the scatterers, eye safety was able to be secured by generating multiple scattering a few times to several tens of times as the aforementioned transport optical depth L/l_{AVE} in a millimeter-order extremely minute multiple scattering optical system.

occurs during the operation of the light source device, it is needless to say that similar operation is effected on an attempt to use the light source device after the damage has once occurred.

[0095] Moreover, an optical communication module of this invention is characterized in that the aforementioned light source device is used as a the transmission means.

[0096] According to the optical communication module, by employing the light source device as the transmission means and further employing, for example, an Si photodiode as a light reception means, there can be provided an optical communication module that satisfies the Class 1 eye safety and concurrently is most inexpensive and excellent in electric optical characteristics for wireless optical communications. Moreover, particularly in an optical communication module, the first region of the multiple scattering optical system is formed as a minute region located adjacent to the light source element (semiconductor laser). Therefore, even when the device is integrated with or formed into an integrated module with a photodiode, the reception system does not suffer the disadvantages of sensitivity degradation and so on. Therefore, by forming an optical communication module by a combination of an inexpensive Si photodiode with the light source device of this invention, there can be provided an optical

represents the full width at half maximum of the near-field pattern, and the parameters, which change this, are the height of silicone gel (204 shown in Fig. 2) after being hardened and the particle size, refractive index and dispersion density of each scatterer. As shown in Fig. 3A, as a general tendency, by increasing the height of the silicone gel and reducing the particle size or increasing the density of the scatterers, the speckles are reduced when the optical depth or the transport optical depth is increased. Although no detailed description is provided for the comparison of individual data, the following matters have become clear.

[0152] With regard to the combination of the thickness in the optical axis direction of the first region in which the transport optical depth (= geometrical dimension L/transport mean free path l_{AVE}) becomes a few times to several hundreds of times or, in particular, a few times to several tens of times with the filler from the distribution of the particle size mode Ds with respect to an identical scatterer, a multiple scattering optical system capable of obtaining the Class 1 level eye safety can be constituted without significantly impairing the output efficiency. Moreover, the effect of sufficiently reducing the speckles cannot be obtained when the dispersion density is smaller than 1 vol% and particularly than 0.1 vol% and conversely

as shown in Fig. 5A. It is possible to obtain a scattering cross section and an asymmetry factor g in accordance with the Mie scattering theory from the scatterer parameters and calculate a transport mean free path l_{AVE} from the dispersion density. In Fig. 5A, the feature also seen in Fig. 3A was observed as a more general tendency without depending on the type of the scatterer. That is, if the transport optical depth exceeds a few times in the first region, which is the multiple scattering region that is brought in contact with the high-power semiconductor laser and is provided so as to surround this, it becomes possible to obtain a near-field pattern in which the speckles are reduced to the level at which the Class 1 level eye safety is satisfied.

[0164] However, if the rightward-sloping tendency is pursued, there are also constraints on the range in which the parameters (refractive index difference and particle size) of the scatterer itself can be changed, and eventually, the dispersion density cannot help being increased to, for example, 30 Vol% to 50 Vol%. The tendency that the speckle rather increased in the high-density region with any of the scatterers was evidently observed. If the dispersion gel in this case is observed by an optical microscope, the greater part of the scatterers is often found to be brought in contact with one

another into a cluster. Although the upper limit value of the transport optical depth L/l_{AVE} at which the speckles increase again differed depending on the scattering cross-sectional area (i.e., mainly the refractive index difference Δn) standardized by the geometrical cross-sectional area of each scatterer, it was found to be difficult to stably obtain a multiple scattering region such that the multiple scattering is preferably generated several hundreds of times or more times with respect to the dimensions of the portions supposed by this invention.

[0165] The scatterer species preferably applied to the construction of an optical system in which the geometric optical path length can be clearly defined as the multiple scattering optical system of this invention as in, particularly Fig. 1, 2 or 4 is not required to be limited to those shown in Figs. 3A and 5A. For example, in the case where the silicone gel (refractive index to the sodium D line is about 1.40) is used as the base material, CeO_2 and ZrO_2 (refractive index: 2.3) are also suitably used in addition to the styrenic crosslinked polymer (refractive index: 1.59) and TiO_2 (refractive index: 2.6). Alternatively, metal oxides such as ZnO (refractive index: 2.0), Al_2O_3 (refractive index: 1.77) and the like, hydroxides such as $Al(OH)_3$ (refractive index: 1.6) and the like or various glass beads (refractive index: about 1.5 to

through the first region when it is virtually assumed that no scatterer exists, by the transport mean free path l_{AVE} in the first region. The vertical axis of Fig. 8 represents the amount of speckles σ_{PAR} of the near-field pattern. The satisfactory relative light intensity distributions of the near-field patterns of the constructions shown in Figs. 6A, 7A and 7C are shown in Figs. 6C, 7B and 7D, respectively.

[0188] It is evident from comparison of Fig. 8 with Fig. 3A or 5A that the value of the amount of speckles σ_{PAR} has been totally reduced. Moreover, according to the constructions of Figs. 6A, 7A and 7C, it becomes possible to reduce the total thickness of the optical system by effectively increasing the scattering frequency by virtue of the arrangement that the multiple scattering region is surrounded by the recess portion of which the outermost surface is provided by a metal layer even with the same geometrical length. Particularly, there was distinctly confirmed a tendency that the speckles were possibly increased when the transport optical depth exceeded several tens to several hundreds of times by simple conversion due to the increase in the thickness of the first region particularly in the constructions of Figs. 7A and 7C, the tendency being similar to Fig. 5A of the second embodiment.

[0189] Moreover, it was found that a metal oxide such as TiO_2, styrenic polymer and so on, in which the size

WHAT IS CLAIMED IS:

1. A light source device having a light source element from which output light is emitted to outside via a multiple scattering optical system, wherein

the multiple scattering optical system includes at least a first region that is located adjacent to the light source element, and a second region that abuts on the first region and reaches the outside, and

of the first and second regions, at least the first region contains scatterers, and a density of the scatterers in the first region is higher than a density of scatterers in the second region.

2. The light source device as claimed in claim 1, wherein

the second region has a lens portion.

3. The light source device as claimed in claim 2, wherein

the lens portion serves as a magnifier for at least a principal portion of a secondary planar light source formed at an interface between the first region and the second region.

4. The light source device as claimed in any one of claims 1 through 3, wherein,

assuming that a size parameter q, which represents a relation between a particle size mode Ds of the scatterers and a center wavelength λ in a base material of the first region of the light source element, is expressed by:

$$q = (2\pi/\lambda)\cdot(Ds/2),$$

then the particle size mode Ds of the scatterers is within a range that allows the size parameter q to fall within a range of approximately 1 - 50, and at least the first region includes a portion where the scatterers are dispersed at a high density so that an average nearest neighbor distance of the scatterers becomes equal to or smaller than twenty times the particle size mode Ds of the scatterers.

5. The light source device as claimed in any one of claims 1 through 4, wherein

the first region employs a gel-like or rubber-like material as the base material.

6. The light source device as claimed in any one of claims 1 through 5, wherein

the device comprises a recess portion having a wall surface and a bottom surface that define the first region, wherein a metal layer is formed on at least part of the wall surface and/or of the bottom surface, and the light source element is directly or indirectly fixed to the bottom surface, and

a surface of the metal layer formed on the at least part of the wall surface and/or of the bottom surface of the recess portion serves as a reflective surface to scattered light of the output light from the light source element.

7. The light source device as claimed in claim 6, wherein

the metal layer on the at least part of the wall surface and/or of the bottom surface of the recess portion is continuously formed so that substances other than the metal are not exposed in a principal portion positioned within reach of the scattered light spatially distributed in the first region.

8. The light source device as claimed in claim 6 or 7, wherein

the surface of the metal layer formed on at least part of the wall surface of the recess portion serves as a

reflective surface that changes an optical axis direction of an outgoing beam of the light source element toward an interface between the first and second regions, and

the size parameter q of the first region falls within a range of approximately 1 to 15.

9. The light source device as claimed in claim 6 or 7, wherein

the surface of the metal layer formed on at least part of the wall surface of the recess portion serves as a reflective surface that changes an optical axis direction of an outgoing beam of the light source element a plurality of times, and

the size parameter q of the first region falls within a range of approximately 10 to 50.

10. The light source device as claimed in claim 9, wherein

an opening of the recess portion has a diameter larger than that of the bottom surface, and

assuming that a ratio of a depth to the diameter of the bottom surface of the recess portion is given as an aspect ratio, r, and an angle made between a normal line of the wall surface of the recess portion and the optical axis

of the outgoing beam of the light source element is θ [deg], then a condition expressed by:

$$\max\{2r, 3\} \leq \theta \leq 20r$$

is satisfied.

11. The light source device as claimed in claim 9, wherein

at least part of the wall surface of the recess portion forms a cylinder whose top and bottom have approximately same sectional configurations, and

assuming that a ratio of a depth to a diameter of the cylinder of the recess portion is given as an aspect ratio, r, and an angle made between a normal line of the wall surface of the recess portion and the optical axis of the outgoing beam of the light source element is θ [deg], then a condition expressed by:

$$\max\{\mathrm{atan}(r/5), 3\} \leq \theta \leq \mathrm{atan}(r/2)$$

is satisfied.

12. The light source device as claimed in any one of claims 1 through 10, wherein

the light source element is a semiconductor laser.

13. The light source device as claimed in claim 12, wherein

the semiconductor laser has an active layer including an InGaAs layer on a GaAs substrate and an emission wavelength within a range of from 880 nm to 920 nm inclusive.

14. The light source device as claimed in claim 13, wherein

the semiconductor laser has the active layer including the InGaAs layer on the GaAs substrate and includes at least one of a ternary layer or a quaternary layer which are expressed by $In_XGa_{1-X}As_YP_{1-Y}$ ($0 \leq X < 1$, $0 < Y < 1$).

15. The light source device as claimed in any one of claims 12 through 14, wherein

the semiconductor laser has spatial fluctuations in at least one of its composition or its layer thickness.

16. The light source device as claimed in claim 14, wherein

the semiconductor laser has the active layer including the InGaAs layer on the GaAs substrate and includes at least one of a ternary layer or a quaternary

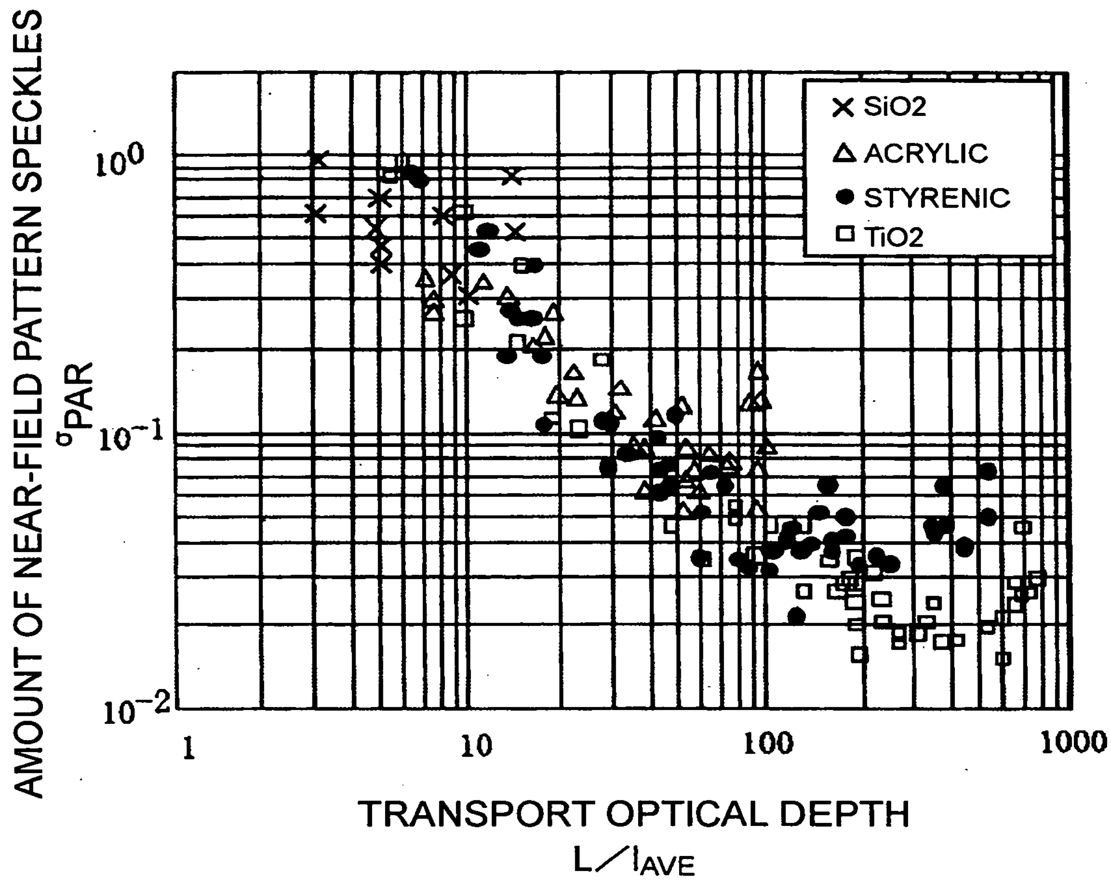
layer expressed by $In_XGa_{1-X}As_YP_{1-Y}$ ($0 \leq X < 1$, $0 < Y < 1$) which has spatial fluctuations in its composition.

17. The light source device as claimed in any one of claims 1 through 16, wherein

at least part of a wire connected directly or indirectly to the semiconductor laser exists inside the second region.

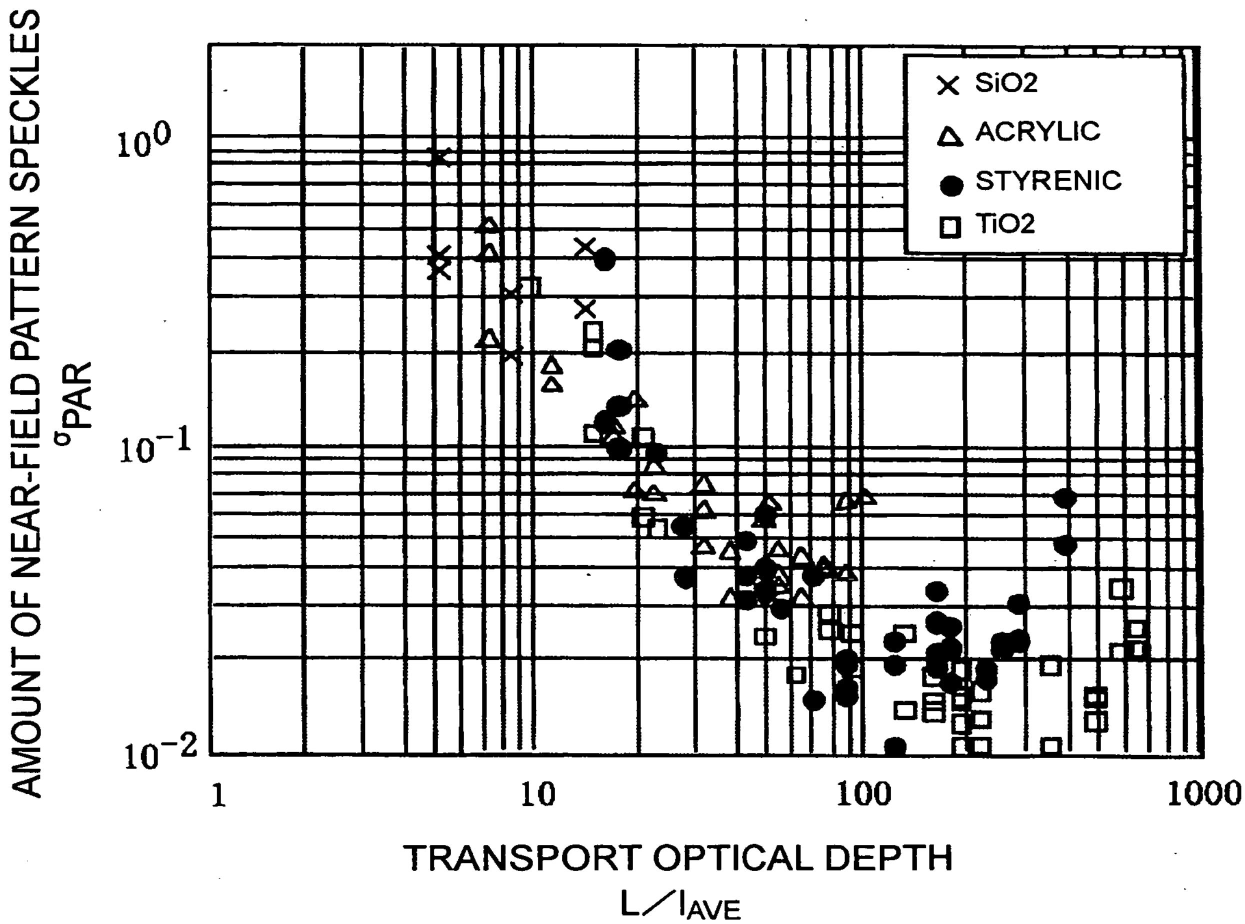
18. An optical communication module employing the light source device claimed in any one of claims 1 through 17 as a transmission means.

Fig. 5A



AMOUNT OF NEAR-FIELD PATTERN SPECKLES
σPAR
10^0
10^-1
10^-2
1
10
100
1000
SiO2
ACRYLIC
STYRENIC
TiO2
TRANSPORT OPTICAL DEPTH
L／lAVE

Fig. 8


AMOUNT OF NEAR-FIELD PATTERN SPECKLES
σPAR
10^0
10^-1
10^-2
1
10
100
1000
TRANSPORT OPTICAL DEPTH
L/lAVE
SiO2
ACRYLIC
STYRENIC
TiO2